MARINE VESSELS

This document presents the proposed guidelines for The Carl Moyer Memorial Air Quality Standards Attainment Program (Carl Moyer Program) for marine vessels. It also contains a brief overview of the marine vessel industry, NOx emission inventory based on emissions calculated for the South Coast Air Basin, current emission standards, available control technology, potential incentive projects eligible for funding, recommended emission reduction calculations, and estimated cost benefits.

A. Introduction

Marine vessel engines contribute to emissions of NOx, HC, CO, PM, and SOx. Marine vessel traffic consists of foreign and domestic (U.S. based) fleets. Emissions from marine vessel engines are generated in California during vessel travel through defined California coastal waters, vessel calls on California ports, as well as from other vessel activities in and near the ports such as fishing, tugboat operations and work boats. The coastal water boundary for California consists of a range from 27 miles off of the California coast at the narrowest, to 102 miles off the coast at the widest (Figure 1 shows this boundary). There have been recent actions on both the international and national level to address the emissions from marine vessel engines. While some strategies being discussed for the South Coast Air Basin may generate emission reductions in the near-term, the full effects from the international and national emission control programs won't be realized for many years since these regulations apply, with certain exceptions, to new engines.

The Carl Moyer Program presents a timely opportunity to realize emission reductions from marine vessels within the next 2-5 years. By providing marine vessel owners with incentive funds for voluntarily reducing NOx emissions from marine vessel engines before mandated regulatory controls are effective, this program has the potential to generate near-term emission reductions from the marine fleet. These emission reductions, in turn, will benefit the local air quality districts' efforts to meet the health based air quality standards.

B. Program Guidelines

The proposed marine vessel incentive guidelines are designed to provide districts and ports with criteria for evaluating reduced-NOx marine vessel projects that are submitted to them for receiving incentive funding. Reduced-NOx marine vessel engine projects that include new, repowered, or retrofitted engines will be considered and closely evaluated as qualifying for incentive funding. For the most part the criteria for selecting a project will depend on the amount of emission reductions, cost effectiveness, and the potential for the project to materialize within a realistic timeframe. These guidelines will provide districts, ports, and program operators with a method for calculating emission reductions and cost effectiveness resulting from reduced-NOx marine vessel projects. In general, marine vessel projects qualifying for evaluation would need to meet the following criteria:

- Thirty percent reduction in NOx emissions from uncontrolled baseline emissions, and beyond what is required by any, national or international regulations;

- Reduced emission levels that must be maintained for a minimum of 5 years; and

- Cost effectiveness no more than $12,000/ton of NOx reduced in California Coastal waters.

C. Emission Inventory

The marine vessel source category includes ocean-going vessels and harbor vessels exclusive of those used in recreational activities. Marine vessel fleets range in power, from approximately 500 to 67,000 horsepower. Marine vessels, for the most part, are propelled by diesel engines and to a smaller extent by steam turbines, or gas turbines. In 1993, approximately 95 percent of the vessels calling on the San Pedro Bay Ports were propelled by diesel engines, with the remaining 5 percent propelled by steam turbines.

1. Marine Vessel Categories and Vessel Types

The marine vessel category includes ocean going vessels, tugboats and other harbor vessels (i.e. work boats, pilot boats, passenger cruise boats, etc.), fishing vessels, U.S. Navy vessels, and U.S. Coast Guard vessels. Typical lifetime for a marine vessel engine is approximately 30 years, with rebuilds occurring about every five years.

2. NOx Emission Inventory

The emission inventory for the South Coast Air Basin shows significant NOx emissions coming from ocean-going vessels, tug boats, harbor vessels, fishing vessels, U.S. Navy and coast Guard, and transiting vessels. In 1993 approximately 1,500 vessels made 5,500 calls on the San Pedro Bay Ports in the South Coast. Approximately 94 percent of the 1,500 vessels were foreign and six percent were U.S. vessels. Estimated emissions from these engines are calculated for both the main engines and the auxiliary power engines operating in either or all of the following modes:

- Cruising,
- Maneuvering, and
- Hotelling

Baseline NOx emissions for 1990 are estimated to be approximately 32 tons per day in the South Coast Air Basin (SCAB). In 2010, NOx emissions are expected to be approximately 52 tons per day in the SCAB which is approximately eight percent of total mobile source NOx emissions for that year. Table 1 lists 1990, 1996, and 2010 estimated NOx emissions from marine vessel engines in the South Coast and statewide.

Table 1
Baseline NOx Emissions
(tons/day)

Area	1990	1996	2010
South Coast	32	41	52
Statewide	58	66	79

Emission estimates from the ARB's emission inventory.

D. Emission Standards

At the international level, the International Maritime Organization (IMO) recently adopted Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78). This protocol, which will enter into force twelve months after 15 countries representing 50% of the commercial tonnage have become parties to the protocol, will reduce NOx emissions from new engines installed on ships after January 1, 2000. At the national level, the U.S. EPA is expected to propose regulations in late 1998 to limit the emissions from domestic vessels not subject to the IMO standards. In addition, the U.S. EPA has been exploring potential control options for reducing the emissions from marine vessels in the South Coast Air Basin to fulfill U.S. EPA's obligation for Measure 13 (M-13) in the 1994 Ozone State Implementation Plan. These discussions have focused on a wide variety of emission reduction strategies including operational controls in the basin such as voluntary speed reduction and moving of the shipping channels as well as port infrastructure improvements and strategies to retrofit engines on harbor vessels. Table 2 lists the IMO standards for NOx emissions.

Table 2
IMO NOx Standards
Effective January 1, 2000

Engine Speed, n	NOx (g/kW-hr)	NOx (g/bhp-hr)
N < 130	17	12.7
1 130 < n < 2000	$45 * n^{-0.2}$ = 17.0 at 130 rpm and 9.8 at 1999 rpm	= 12.7 at 130 rpm and 7.3 at 1999 rpm
n = 2000 +	9.8	7.3

Source: U.S. EPA, 40 CFR Part 89, Control of Emissions of Air Pollution from New CI Marine Engines at or above 37 Kilowatts, May 11, 1998.

MARPOL 73/78 prevents U.S. EPA from setting lower emission standards for engines on marine vessels traveling to or from foreign countries. U.S. EPA has the authority to propose marine vessel standards for domestic vessels that remain in national waters. As such, U.S. EPA proposed marine standards in May 1998 for domestic vessels not subject to IMO standards. The proposed federal marine standards mimic the IMO standards for engine speeds that are less than 2,000 rpm. For marine engine speeds that are greater than 2,000 rpm, however, U.S. EPA has proposed standards similar to U.S. EPA's current Tier 1 emission standard for locomotive engines (9.2 g/bhp-hr).

E. Control Technology

Marine vessel engines in tugboats and fishing vessels are very similar to locomotive and heavy-duty truck-type engines. Marine vessel engines are costly and designed to last a long time. Typical lifetimes are about 30 years. Over this period, engines are overhauled at regular five-year intervals. Since they are often overhauled regularly, applying control technologies at the point of overhaul would be the least disruptive and least costly approach. The technology required to meet lower NOx emissions are somewhat similar to those for on-road heavy-duty vehicle and locomotive control technology. Technologies include exhaust aftertreatment, and advanced technologies that have been applied to on-road engines. Dual fuel natural gas retrofit kits are available that could lower NOx emissions from marine vessel engines (fishing boats) by about 30 to 40 percent. Selective catalytic reduction (SCR) which is used for land based applications, could also be used on vessels. There are about eight marine vessels with SCR.

F. Potential Types of Projects

Typical projects that would qualify for incentive funding under these guidelines would include the use of retrofit kits or repowers to lower NOx emissions, the purchase of new reduced-NOx marine engines, or the purchase of reduced-NOx portside equipment. Since many ocean-going vessels do not call on ports frequently during the year, controls may not be as cost effective for these vessels. For the most part, cost effective projects will be those that include controls incorporated on vessels that frequent the ports or remain in the harbor. These types of vessels include, but are not limited to, tugs, crew/supply boats, and fishing boats.

Projects consisting of new marine vessel engines that produce reduced-NOx emissions would also be considered for funding. However, incremental costs for new engines may be too high to qualify this type of project as cost effective.

Projects consisting of reduced-NOx portside equipment could also be considered for incentive funds. These types of projects would be less costly, compared to marine engine control. However, NOx emission reductions and cost effectiveness would depend on the amount of operation hours from these types of equipment. The types of equipment, as well as the extent of operation, could vary considerably in each port. Hence, these types of projects would need to be evaluated individually to determine the project eligibility.

1. Repowers & Retrofits:

Repowering could occur during engine rebuild by exchanging a marine vessel's old engine for a newer, lower-emission engine. Retrofit involves hardware modifications to the engine, so the modified engine emits less emissions. The conversion could occur by adding on control equipment to convert the engine to a reduced-NOx engine technology. In both cases, funding eligibility will be evaluated based on the amount of emissions reduced and a maximum cost effectiveness of $12,000 per ton. Furthermore, the cleaner engine would need to test to an emission limit that is at least 30 percent lower then uncontrolled baseline NOx emissions. If a baseline emission limit is not available by the applicant, an average baseline uncontrolled emission factor will be used when calculating emissions. These factors were provided to ARB by the South Coast Air Quality

Management District and are listed in Tables 3 through 6. The emission level will have to be maintained for a minimum of 5 years (project life).

Table 3
Marine Vessel Emission Factors for all Design Categories
(lbs/1000 gal)

Vessel Type	Propulsion Type	Cruise		Maneuvering	
		Baseline NOx	30 Percent Reduction in NOx	Baseline NOx	30 Percent Reduction in NOx
Auto Carrier	Motorship	587	411	587	411
Bulk	Motorship	641	449	641	449
	Steamship	64	45	56	39
Container	Motorship	643	450	643	450
	Steamship	64	45	56	39
Gen.Cargo	Motorship	603	422	603	422
Passenger	Motorship	535	375	535	375
	Steamship	64	45	56	39
Refer	Motorships	612	428	612	428
Roro	Motorships	630	441	630	441
	Steamships	64	45	56	39
Tanker	Motorships	639	447	639	447
	Motorships	64	45	56	39

Table 4
Marine Vessel Auxiliary Power Emission Factors for all Design Categories
(lbs/hour)

Vessel Type	Propulsion Type	Auxiliary Power	Baseline NOx	30 Percent Reduction in NOx
All	Motorship	Engines	14.7	10
		Boilers	2.7	2
	Steamship	Main Boilers	19.6	14

Table 5
Harbor Vessel Emission Factors – Medium Speed Diesels
(lbs/1000 gal)

Vessel Type	Baseline NOx	30 Percent Reduction in NOx
Tug/tow/push boats, passenger/excursion boats, work/supply/utility boats, fishing vessels	419	293

Table 6
U. S. Navy Ship Emission Factors
(lbs/1000 gal)

Vessel Type	Baseline NOx	30 Percent Reduction in NOx
Motorship	652	456
Steamship	64	45

2. Portside Equipment Repowers & Retrofits

Projects that consist of portside equipment engine repowers and retrofits could also qualify for incentive funds. Similar to marine vessel engine repowers and retrofits, these projects will be evaluated based on the amount of emissions reduced and a cost effectiveness of at most $12,000 per ton. However, the cleaner engine would need to reduce NOx emissions to levels listed in the off-road equipment guidelines. In addition, the new certified emission level will have to be maintained for a minimum of 5 years (project life).

3. Sample Project Application Forms

In order to qualify for incentive funds, districts or ports will make applications available and solicit bids for reduced-emission projects from marine vessel owners. The ARB could also grant funds directly to locomotive and marine projects. In either case, a sample application has been provided in Attachment A. The applicant should provide at least the following information:

1. Company Name	13. % Operated in California
2. Project Name	14. Type of fuel used
3. District	15. Type of Engines:
4. Vessel Type: auto carrier, bulk carrier, container Ship, general cargo, passenger ship, reefer, RORO, tanker, tug/tow/push boat, Work/supply/utility boats, fishing vessel, U.S Navy ship	16. Annual number of Port Calls in California
5. Propulsion Type: motorship, or steamship	17. Avg. time (hours) per port call in each service mode:

	a. Cruise b. P-zone Cruise c. Maneuvering d. Hotelling
6. Ship Service Speed	18. Average Nautical Miles per port call within California coastal water boundary
7. Ship Deadweight Tonnage (DWT)	19. Project Life (min. 5 years)
8. Avg. fuel consumption (gallons) per port call for Each service mode: a. Cruise b. P-zone Cruise c. Maneuvering d. Hotelling	20. Avg. fuel consumption (gallons) per port call for Auxiliary Power: a. Boilers (motorship) b. Engines (motorship) c. Main boilers (steamship)
9. Capital cost of remanufacture w/out control	21. Annual number of Port Calls in a Port
10. Capital Cost of remanufacture with control	22. Baseline NOx Emissions
11. Matching Funds	23. New Lower NOx Emissions
12. Incentive Amount Requested	

G. Emission Reductions and Cost-Effectiveness

According to the following guidelines, the amount of incentive funds granted would depend on the amount of emission reductions. Only projects that have a cost effectiveness of at most $12,000/ton of NOx reduced will qualify for incentive funding.

1. Emission Reduction Calculation

Emission reductions for marine vessel engines are based on annual fuel consumption, and percent operated in California coastal waters. As discussed previously, the California coastal water boundary consists of a range from 27 miles off of the California coast at the narrowest to 102 miles off the coast at the widest.

NOx emission reductions for a project are based on the amount of annual fuel consumed for the main engines, and the auxiliary power, depending on the vessel type. Fuel consumption is multiplied by a specific NOx emission factor and then converted to tons per year. Emission factors for each engine is based on vessel type, propulsion type, and service mode. Average emission factors for uncontrolled baseline NOx emissions listed in Tables 3 through 6 above can be used where actual uncontrolled baseline emissions are not known. The following formula would be used when calculating project NOx reductions.

Annual NOx Reductions (tons/year) =
[(Ann. Fuel Cons.) * [(Baseline NOx Emissions) - (Controlled NOx Emissions)] * (% operated in CA)] / (2,000 lbs/ton)

where,

Ann. Fuel Cons	=	Estimated Annual Fuel consumption for the retrofitted/repowered engine(gal/year)
Baseline NOx Emissions	=	NOx Emissions from the overhauled engine (without retrofit/repower)

Controlled NOx Emissions	=	NOx Emissions from the new engine
% operated in CA	**=**	The percent of time operated in California
2,000 lbs/ton		Converts grams/year to tons/year

For the purposes of explaining the emission reduction calculation for a particular marine vessel project, consider an owner faced with the opportunity to replace one tugboat engine perhaps during the normal engine overhaul period. In this case, the marine owner applies for funding to repower one 4000 hp tugboat engine with a low emission diesel engine. The repowered engine reduces uncontrolled NOx emissions by 40 percent, with a project life of about five years. The marine vessel owner estimates that the capital cost for rebuilding a 4,000 hp marine vessel engine without the upgrades is about $250,000. The upgrade, however, is more expensive, and estimated to be about $300,000. The marine vessel owner also estimates that the annual fuel consumption for this tugboat in California would be approximately 30,000 gals. Emission reductions are calculated as follows.

Ann. Fuel Cons	=	30,000 gals/year
Baseline NOx Emissions	=	419 lbs/1000 gals (1993 baseline emission factor for tug boat engines provided in Table 5 above)
Controlled NOx Emissions	=	251.4 lbs/1000 gals (40 percent reduction from 419 lbs/1000 gals)
% operated in CA	**=**	1 (i.e. 100% is input as 1, 75% is 0.75, etc.)
2,000 lbs/ton		Converts grams/year to tons/year

Estimated NOx reductions are:

(30,000 gals/year) * [(419 – 251.4)lbs/1000 gals]*(1) / (2,000 lbs/ton) = **2.5 tons/year** for one engine

There is a degree of uncertainty regarding the amount of offshore emissions that actually reach the mainland. For this reason, the staff may recommend an emission discount to apply to offshore emissions. In late 1997, as part of the Southern California Ozone Study, the Tracer Dispersion Study was conducted to determine offshore emission impacts. The results of this study may help staff in quantifying these impacts.

2. Cost-Effectiveness Calculation

Typical marine vessel engine control projects, although technologically feasible, also have higher initial capital cost. Control technologies for a particular vessel will be associated with a certain annual cost each year, but emission reductions will vary from year to year depending on the amount of calls in a port. Emission reductions might even be zero in some years, making some control options less cost effective. Each application will be carefully evaluated on a case by case basis.

The cost benefits are based on the incremental capital cost, any vehicle surcharge matching funds that were used to fund the project, the expected life of the project, the interest rate (five percent), and estimated annual NOx reductions. The discount rate of five percent reflects the opportunity cost of public funds for the Carl Moyer Program. This is the level of earning that could be reasonably expected by investing state funds and is based on the most recent interest rates published.

Incremental costs are determined by considering the difference between the capital cost for overhauling/rebuilding an engine to its original configuration (without improved control technology) and the capital cost to repower the engine or retrofit the engine with new control technology. Incremental costs are divided by the annual NOx reductions and multiplied by a capital recovery factor. This calculation will result in annualized project cost benefits. Cost benefits can be calculated using the following formulas:

Incremental Project Cost = (Aft. Proj. Cap. Cost) - (Bef. Proj. Cap. Cost)

Where, **Aft. Proj. Cap. Cost =** capital costs for reduced-NOx engine
Bef. Proj. Cap. Cost = capital costs for the rebuilt engine without the upgrade

Maximum Amount Funded = (Incremental Project Cost) - (Match Funds)

Where, **Match Funds =** Any vehicle surcharge matching funds

Capital Recovery = $[(1 + i)^n (i)]/[(1 + i)^n - 1]$

Where, i = discount rate (5 percent)
n = project life (at least five years)

Annualized Cost = [(Maximum Amount) + (Match Funds)] * (Capital Recovery)

Cost-Effectiveness = (Annualized Cost) / (Annual NOx Reductions)

Where, **Annual NOx Reductions =** Calculated NOx reductions (tons/year)

Using the above example, the above formulas, and the cost assumptions provided earlier in the Section G-1, the capital costs, the incremental costs and benefits can be calculated as follows:

Capital Costs to rebuild a 4,000 hp marine vessel engine w/o upgrade	$250,000.00
Capital costs to repower a 4,000 hp marine vessel engine	$300,000.00
Matching funds	$ 0.00

Incremental Project Cost = (300,000 - 250,000) = $50,000
Maximum Amount Funded = (50,000 – 0) = $50,000
Capital Recovery = $[(1 + 0.05)^5 (0.05)]/[(1 + 0.05)^5 - 1] = 0.23$
Annualized Cost =[(50,000) + (0)] * (0.23) = $11,500/ year
Cost Effectiveness = (11,500 / year) / (2.5 tons/year)= **$4,600/ ton**

The cost benefit for the example is less than $12,000.00 per ton of NOx reduced. This project would qualify for grant funds.

H. Reporting and Monitoring

During the project life, the district/port must conduct periodic checks of each retrofitted/repowered marine engine operating records. Records must contain, at minimum the following: marine vessel identification numbers; retrofit hardware model and serial numbers; nautical miles traveled in the district and California coastal waters; estimated fuel consumption in California coastal waters; estimated hours of operation in the California coastal waters; hours in idle; and maintenance and repair dates (or any servicing information). Records must be retained and updated throughout the project life and made available for district inspection.